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TRACKING A LASER-PROJECTED HORIZON INDICATOR

J. M. Lentz, G. T. Turnipseed, and W. C. Hixson

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We did not evolve in motion and acceleration environments typical of military aviation, and we lack sense organs to cope with these environments. Even though the vestibular and visual systems function properly in these environments, the brain cannot accurately interpret them without visual or tactile contact with some fixed spatial reference point such as the Earth's horizon. In the airplane, this reference is provided by a gyro-stabilized artificial horizon instrument. Individuals differ widely in their ability to extract visual information from this attitude indicator and mentally integrate it with information from other body sensors. Consequently, failure to assimilate all of this information can result in disorientation, erratic motor performance, or intuitively correct but grossly incorrect control decisions. One of the more promising recent attempts to combat inflight spatial disorientation has focused on the development of Peripheral Vision Horizon Devices (PVHD) suitable for installation in operational aircraft. This paper describes a series of laboratory experiments directed at explaining some of the psychophysiological characteristics of the PVHD that are significant to its operational application.

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SUMMARY PAGE

THE PROBLEM

Spatial disorientation and/or the loss of situational awareness have been identified as the primary or secondary cause of 15-25% of all fatal military aircraft accidents (1,2). One of the most promising recent attempts to combat disorientation has focused on the Peripheral Vision Horizon Device (PVHD). The purpose of the set of experiments described in this paper was to investigate some of the physiological mechanisms on which the PVHD is based.

FINDINGS

These experiments indicated that wide visual-angle artificial horizons are easier to track than narrow horizons. Results from Experiment I suggested that compensatory tracking abilities can be improved by extending the projected artificial horizon so as to stimulate the peripheral retina. Blanking the foveal 8° did not hinder tracking; however, blanking the central 60° did diminish performance (relative to full 90° projection). Experiments II and III confirmed the 'bigger is better' concept while the subject was occupied by additional workload tasks and/or a drug challenge. Experiment IV indicated that extending the projected horizon up to 10-15° of visual angle improved tracking abilities, but further extensions did not significantly improve performance.

RECOMMENDATIONS

Due to the importance of the attitude indicator (ADI) in maintaining aircraft orientation, we recommend that a series of 'small' horizon sizes (e.g., 4-15°) be evaluated for optimal artificial tracking. Doubling the size of the standard ADI may produce a significant increase in tracking ability and possibly aircraft orientation control. Further evaluation of the PVHD, from not only a workload enhancement perspective but also as a disorientation prevention device, is needed. From strictly a tracking point-of-view, a large, projected, artificial horizon (PVHD) can be responded to and controlled in a more accurate manner when compared to the conventional, small-scale, ADI-type, flight instrument.

ACKNOWLEDGMENTS

We thank Andrew Dennis for development of the hardware used in this project, Jeff Wheat for programming assistance, and Iyoko N. Forstall for the Kanji script. We are also indebted to ENS Reed Dunne, ENS John Pritchett, and HM1 Denise Hammerle for providing testing assistance. Dr. Fred E. Guedry, Jr., and Kathy Mayer provided an excellent set of editorial comments. We are particularly indebted to our subjects who gave freely of their time to assist us in this project.

PREFACE

We did not evolve in motion and acceleration environments typical of military aviation, and we lack sense organs to cope with these environments. Even though the vestibular and visual systems function properly in these environments, the brain cannot accurately interpret them without visual or tactile contact with some fixed spatial reference point such as the Earth's horizon. In the airplane, this reference is provided by a gyrostabilized artificial horizon instrument. Individuals differ widely in their ability to extract visual information from this attitude indicator and mentally integrate it with other information. Consequently, failure to assimilate this information can result in disorientation, erratic motor performance, or intuitively correct but grossly wrong control decisions. One of the more promising recent attempts to combat inflight spatial disorientation has focused on the development of Peripheral Vision Horizon Devices (PVHD) suitable for installation in operational aircraft. This paper describes a series of laboratory experiments directed at explaining some of the psychophysiological characteristics of the PVHD that are significant to its operational application.

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INTRODUCTION

Spatial disorientation or the loss of situational awareness have been identified as the primary or secondary cause of 15-25% of all fatal military aircraft accidents (1,2). One of the most promising recent attempts to combat disorientation has focused on the Peripheral Vision Horizon Device (PVHD). The PVHD, which has also been called the 'Malcolm Horizon' (8), presents attitude information (artificial horizon) by means of an elongated beam of laser light, which is projected across the cockpit panel. This device allows attitude information to be processed either by foveal vision (normal mode) or by peripheral vision using the projected LASER horizon. The set of experiments described in this paper was designed to initiate investigation of the physiological mechanisms (3-8) on which the PVHD is based. Experiment I addresses the importance of the central (foveal) portion of the display relative to the peripheral segments. Experiments II and III use a secondary performance task and a drug challenge while simultaneously evaluating long- and short-horizon projections. Experiment IV is a comparison of four horizons, which approximate display sizes used in operational flight instruments. For general information on PVHD development, refer to the proceedings of a recent NASA symposium (9). The use of peripheral vision for instrument flying tasks has also been discussed by Hasbrook (10,11).

EXPERIMENT I

SUBJECTS

Subjects were 24 Navy and Marine Corps flight students ranging in age from 22 to 28 years. All subjects had recently passed a routine flight physical. Two subjects were left-handed.

APPARATUS

To produce an artificial horizon, a low-power (0.43 mW) helium-neon laser was projected on a large (8 ft x 8 ft) rear projection screen. The red (632 nm) laser beam was reflected by a set of galvanometer-driven mirrors using closed-loop, position-mode, scanner amplifiers and an analog computer as shown in Figure 1. The beam was elongated to form an artificial horizon and rotated to produce roll motion. A random, forcing function (Gaussian noise bandwidth .15 Hz, amplitude 3.16 V rms) was used to induce roll of the projected horizon (3.16 V produced a 30° deflection). The lengths and configurations of the horizons were varied by inserting circular photographic film 'masks' between the laser and the screen, occluding unwanted portions of the horizon.

The subject was seated 1 m in front of the screen as shown in Figure 2. The subject's chair was equipped with a headrest and a joystick that was attached to the right armrest. A 30° deflection of the joystick produced a 30° deflection of the horizon. The forcing function and the signal from the joystick were fed to a summing amplifier, and a root mean square (rms) converter summated rms tracking error voltage.

METHOD

The subject was instructed to perform compensatory tracking to keep the projected horizon in a horizontal position. A set of four horizon configurations were used: (1) a long horizon subtending a 90° visual angle, (2) a short horizon subtending 8°, (3) a long horizon (90°) with a 60° center section blacked out, and (4) a long horizon (90°) with an 8° center section blacked out. These configurations are depicted in Figure 3.

A 1-min practice trial was given for each of the four horizons. The subjects then tracked each of the 4 horizons 4 times (16 trials) with each trial lasting 1 min. A 1-min rest period was given between trials, and rms error voltage was recorded following each trial. The order of horizon presentations was counterbalanced across subjects.

RESULTS

A t-test for related measures indicated significantly better tracking using either the 90° horizon or the 90 minus 8° horizon as compared to the 8° horizon or the 90 minus 60° horizon. Results are presented in Table 1.

TABLE 1. Single-task Tracking.

Horizon condition	Respective mean rms error in volts (±1 SD)	t(df = 23)
8 vs 90	50.7 (13.9) vs 46 (12.1)	2.62*
8 vs 90-8	50.7 (13.9) vs 43.7 (10.7)	4.44***
8 vs 90-60	50.7 (13.9) vs 51.9 (14.5)	-0.64
90 vs 90-8	46.0 (12.1) vs 43.7 (10.7)	1.6
90 vs 90-60	46.0 (12.1) vs 51.9 (14.5)	-3.13**
90-8 vs 90-60	43.7 (10.7) vs 51.9 (14.5)	-5.38***

* $p < .05$
** $p < .01$
*** $p < .001$

EXPERIMENT II

SUBJECTS

Eleven Navy or Marine Corps flight students and one naval aviation psychologist volunteered as subjects for this experiment. All subjects had recently passed a flight physical and ranged in age from 24 to 34 years.

APPARATUS

Tracking Task

The compensatory tracking task was identical to that used in Experiment I, with the exception that only two horizon lengths were used (90° and 8°).

Letter Identification

A modified, visual, Sternberg letter-identification task was used as a secondary loading task. This task consisted of identification of 4 positive Kanji letters mixed with 20 negative Kanji letters (Fig. 4). Letters were presented to the center and 4° above the projected horizon. A new letter appeared every 2 s and was visible for 1.4 s. The subject responded to the positive or negative letters using two buttons mounted on the tracking joystick.

METHOD

Single-task

A short training period was used to teach each subject the positive letters. All subjects performed the single-task baseline trials in the following order: (a) letter identification, (b) tracking the long horizon, and (c) tracking the short horizon. Each of the single-task trails was performed 4 times, yielding a total of 12 trials. Thirty letters were presented randomly during each 1-min trial with an equal number of positive and negative letters. A 1-min rest period was given between trials, and the order of presentations was counterbalanced. The number of correct, incorrect, and omitted responses, or rms tracking error, was recorded following each trial.

Dual-task

The dual-task trials involved compensatory tracking using the long or short horizon and were performed simultaneously with letter identification. Each condition was presented four times with a 1-min rest period between trials, and the order of presentation was again counterbalanced across subjects. The number of correct, incorrect, and omitted responses was recorded along with rms error after each trial.

RESULTS

Performance on the letter identification task did not significantly vary across the testing conditions. Single-task tracking was marginally better (but not statistically significant) using the 90° versus the 8° projected horizon ($t = 1.48$, $df = 11$, $p =$ NS). In contrast, dual-task tracking was significantly better using the 90° versus the 8° horizon ($t = 4.57$, $df = 11$, $p < .001$). Results are shown in Table 2.

TABLE 2. Dual-task Tracking with Letters.

Letter Recognition

Condition	Respective number of correct letters (± 1 SD)	t (df = 11)
Letters vs letters & 8	26.9 (1.9) vs 27.2 (1.6)	-0.99
Letters vs letters & 90	26.9 (1.9) vs 27.5 (1.9)	-1.65
Letters & 8 vs letters & 90	27.2 (1.6) vs 27.5 (1.9)	-1.14

Tracking

Condition (Number refers to horizon size)	Respective rms error in volts (± 1 SD)	t (df = 11)
Letters & 8 vs letters & 90	59.8 (10.2) vs 51.7 (10.2)	4.57***
Letters & 90 vs 90	51.7 (10.2) vs 41.4 (9.3)	-5.76***
Letters & 8 vs 8	59.8 (10.2) vs 44.3 (12.3)	-3.89***
8 vs 90	44.3 (12.3) vs 41.4 (9.3)	1.48

* $< .05$
** $< .01$
*** $< .001$

EXPERIMENT III

SUBJECTS

Subjects were nine U. S. Navy enlisted men ranging in age from 18 to 30 years. All subjects had recently passed Navy physicals. One additional subject was a 35-year-old naval officer, also in good health.

APPARATUS

Tracking Task

The compensatory tracking test was essentially the same as in Experiments I and II, with the exception that the projected horizon configurations were changed to subtend visual angles of either 30° or 4°. Additionally, a slide of the rear instrument panel of an F-16B aircraft was projected life-size on the screen in front of the subject with the laser horizon superimposed. The analog computer, used to produce roll and tracking error, was replaced with a microprocessor, and the rms converter

was replaced with an A/D converter and a mini-computer to compute rms error. The amplitude of the forcing function was reduced to 1.0V rms to reduce the complexity of the task(s).

Letter Identification

Four positive English letters and 20 negative English letters were added to the Kanji letters used in Experiment II (Fig. 4). These letters were presented 30° to the subject's right and left in an alternating fashion. A new letter appeared every 2 s and was visible for 1 s. The subject responded to the positive or negative letters by using two foot-switches. The subject was instructed to maintain his head in a forward-looking position, and a small baffle was placed on the subject's nasion to prevent each eye from seeing the letter in the opposite visual field. The visual baffle was evaluated for use in a potential hemispheric processing experiment and was not related to the results of this experiment.

METHOD

Single-task

Subjects were tested under both medicated (2 mg atropine I.M.) and non-medicated (saline) conditions on separate days. A short training period was used to teach each subject the positive letters. All subjects were given one practice trial on the single-task, baseline trials in the following order: (1) letter identification using the right foot to respond, (2) letter identification using the left foot to respond, (3) tracking the short horizon, and (4) tracking the long horizon. Each of the single-task trials was then performed once. Forty letters were randomly presented during each 80-s, letter identification trial with an equal number of positive and negative English and Kanji letters. Subjects were given a 1-min rest between trials, and the order of presentation was counterbalanced across subjects. The same order of testing was used each test day for any given subject. Subject performance measures recorded for each trial included the number of correct, incorrect, and omitted responses and the corresponding response times or rms tracking error.

Dual-task

The dual-task consisted of compensatory tracking, of either the long or short horizon, performed simultaneously with letter identification using a right- or left-foot response. Each combination was presented once for a total of four trials. Each 80-s trial was followed by a 1-min rest period with the order of presentation counterbalanced.

RESULTS

Comparison of Compensatory Tracking

Compensatory tracking using the long horizon (30°) was significantly better than tracking with the short horizon (4°) for three of the four experimental conditions. Significant improvements afforded by the longer horizon were present for both saline and atropine administration and for both single-task (atropine $t = 4.79$, $df = 9$, $p < .0001$; saline $t = 1.7$, $df = 9$, $p =$ NS) and dual-task (atropine $t = 3.23$, $df = 9$, $p < .01$; saline

t = 3.59, df = 9, $p < .01$) test conditions. Atropine did not affect single- or dual-task compensatory tracking as shown in Table 3.

TABLE 3. Summary Data for Single- and Dual-task Performance Main Effects Comparisons, Mean (± 1 SD).

	F	p
ANOVA - Single-Task/Reaction Times		
Atropine .866 (.174) vs saline .870 (.146)	0.01	NS
Right foot .844 (.154) vs left foot .892 (.163)	7.57	.02
English .829 (.149) vs Kanji .908 (.161)	110.48	.001
Right field .871 (.162) vs left field .865 (.158)	2.62	NS
+ Letters .860 (156) vs - letters .876 (.164)	5.61	.04
ANOVA - Dual-Task/Reaction Times		
Atropine .926 (.163) vs saline .947 (.155)	0.78	NS
Right foot .943 (.162) vs left foot .930 (.157)	3.25	NS
Short horizon .927 (.145) vs long horizon .947 (.172)	1.48	NS
English .882 (.141) vs Kanji .991 (.159)	149.47	.001
Right field .937 (.159) vs left field .936 (.160)	0.46	NS
+ Letters .930 (.161) vs - letters .943 (.158)	3.98	NS

Reaction Times

Forty reaction times were recorded for each subject for each of 16 conditions (combinations of single/dual task, dosage, responding foot, and horizon). Times outside of ± 2 standard deviations and incorrect responses were discarded. Times were then sorted into 8 ranges for each of the 16 conditions. A mean and standard deviation was computed for the five response times for each subject for each variable. These subject means were used to compute the means for the group and single- and dual-task ANOVAs.

Atropine had no effect on reaction times. Reaction time increased significantly for the Kanji versus English letters for both single-task (F (1,9) = 110, $p < .001$) and dual-task (F (1,9) = 149, $p < .0001$) conditions. Main effect comparisons are shown in Table 3.

EXPERIMENT IV

SUBJECTS

Subjects were 24 Navy and Marine Corps flight officer students ranging in age from 22 to 28 years. All subjects had recently passed a flight physical.

APPARATUS

The compensatory tracking task was similar to that used in Experiment III; however, a pitch component was added to the task. The joystick gain was the same for both axes; (30° deflection of the joystick produced 30° deflection of the horizon) although the forcing function amplitude for pitch (0.5 V rms) was half that of roll (1.0 V rms). The horizon configurations were changed to subtend 3.8, 9, 16, or 30°. The 3.8° horizon subtended the same visual angle as the backup attitude indicator (ADI) in the F-16B aircraft; the 9° projection approximated the head-up display (HUD) width in the F-16B; the 16° horizon approximated the HUD width for the F-18; and the 30° horizon was an average width of a Malcolm Horizon projection.

METHOD

Subjects were tested for 5 days, one session per day. Each session consisted of one 4-min trial at each horizon length with a 90-s rest between trials. The order of presentations was counterbalanced, and each subject received the same order of presentations each day.

RESULTS

Tracking ability improved significantly across the 5 days for both roll ($\underline{F}$ (4,92) = 58.9, $\underline{p}$ < .001) and pitch ($\underline{F}$ (4,92) = 66.4, $\underline{p}$ < .001) axis perturbations (Fig. 5). The four horizon sizes were significantly different for roll axis tracking ($\underline{F}$ (3,69) = 88.6, $\underline{p}$ < .001) but not for pitch axis tracking.

GENERAL DISCUSSION

These experiments indicate that the wide visual-angle artificial horizons are easier to track than the narrow horizons. In Experiment I, the 90 and/or 90 minus 8° horizons were tracked significantly better than the 8° or the 90 minus 60° horizons. These results suggest that visual inputs from the peripheral retina enhance tracking abilities. Blanking the foveal 8° did not hinder tracking; however, blanking the central 60° (90 minus 60°) did diminish performance. One explanation of these results is that optimal PVHD tracking ability is dependent on rod distribution. Rod density in the foveal 8° is low; it peaks at approximately 18-20° and rapidly diminishes beyond 30° from the fovea. The limited number of rods stimulated by the 8° and 90 minus 60° horizons might account for diminished tracking relative to the 90° and 90 minus 8° horizons, which stimulate more rods.

Experiments II and III confirmed the 'bigger is better' concept while the subject was occupied by additional workload tasks and/or drug challenge. Theoretically, the PVHD reduces workload by allowing the pilot to parallel process visual information, e.g., allowing his cockpit scan pattern to either include additional instruments or to increase the frequency of scan for primary instruments. Neither experiment supports these suppositions, since performance on the secondary task (Sternberg letter identification) was nearly perfect in all testing conditions. A more difficult secondary task will be needed to evaluate any potential workload advantage.

In Experiment IV, we compared several operationally meaningful horizon sizes. Tracking improved significantly when the subject shifted from the 3.9° horizon (backup ADI in the F-16B) to the 9°, 18°, or 30° horizons. Performance on the latter three horizon sizes was basically the same, although it improved somewhat with increasing size.

Is there an optimal PVHD (or ADI) size? Apparently, the 'bigger is better' approach has merit; however, performance may not dramatically improve as the artificial horizon is extended beyond $10\text{-}15^{\circ}$ of visual angle. Although this finding does not totally support the preceding discussion on rod density, it does support the importance of parafoveal stimulation.

Due to the importance of the ADI in maintaining aircraft orientation, we recommend that a series of 'small' horizon sizes (e.g., $4\text{-}15^{\circ}$) be evaluated for optimal tracking. Doubling the size of the standard ADI may produce a significant increase in tracking ability and possibly aircraft orientation control. Additional experimental work evaluating the PVHD from not only a workload enhancement perspective but also as a disorientation prevention device is needed. From strictly a tracking point-of-view, performance with a large projected artificial horizon (PVHD) was superior to performance with the small, commonplace ADI-type instrument.

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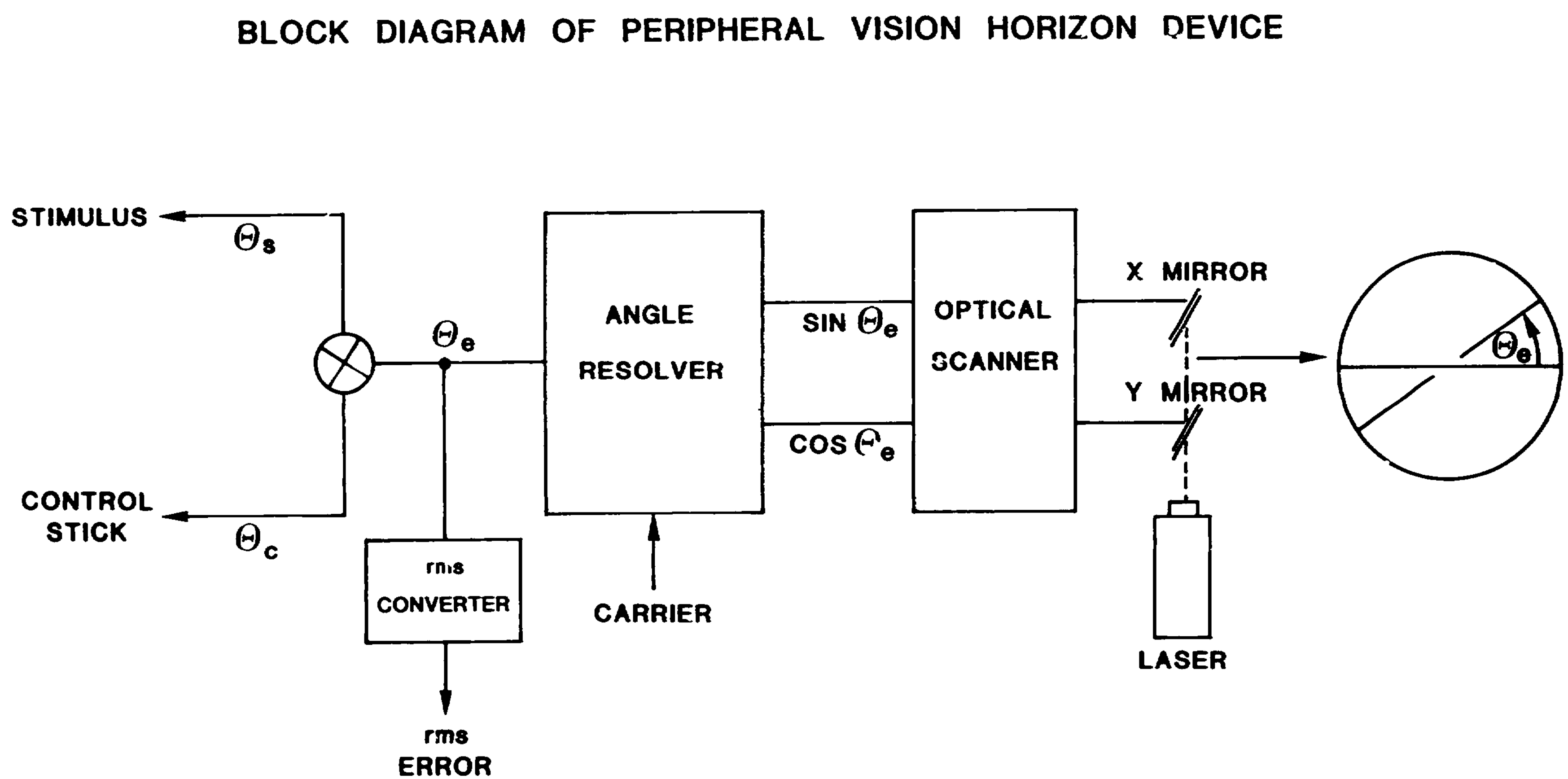

Figure 1. Electromechanical configuration used to generate the laser-projected horizon.

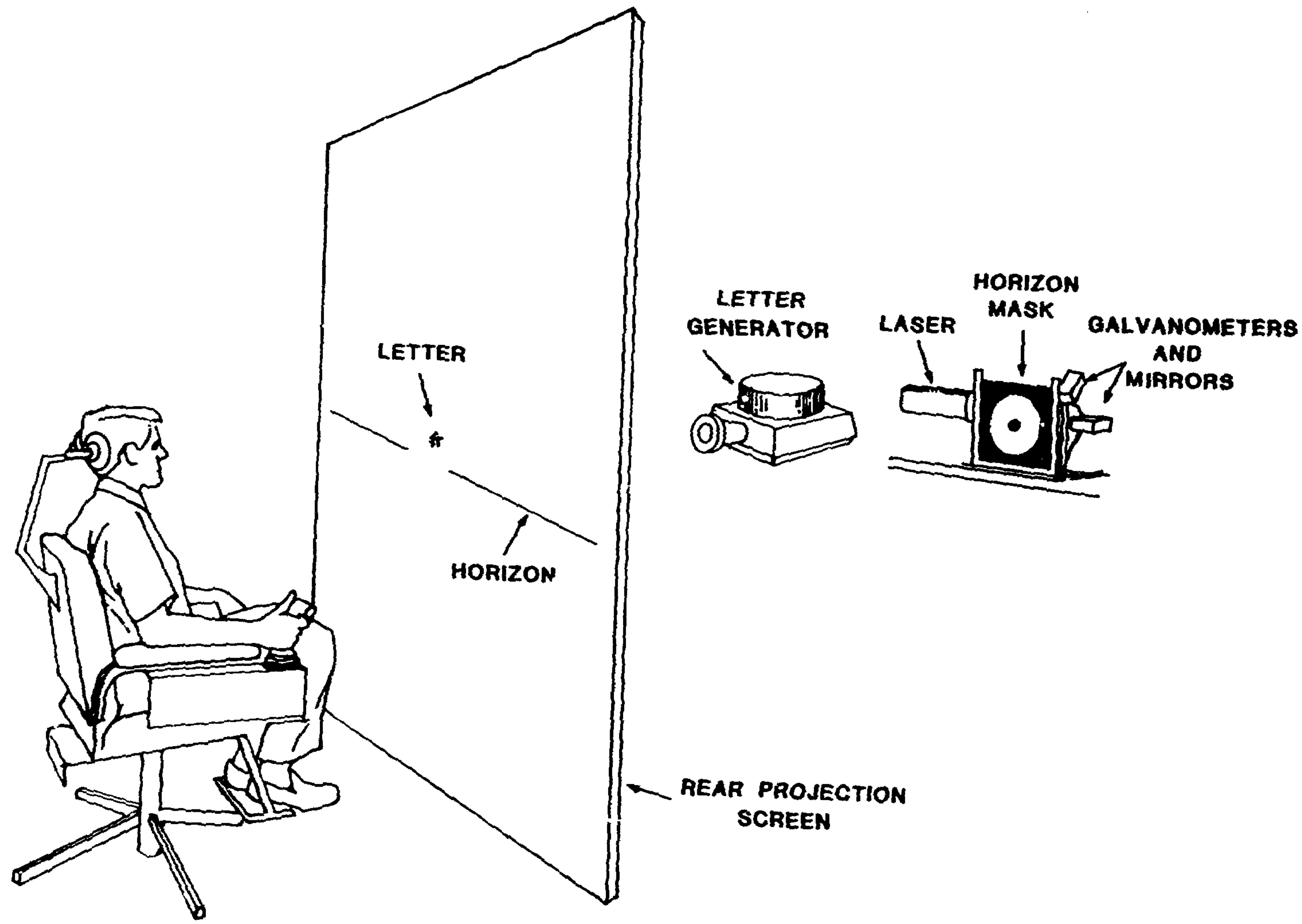

Figure 2. Experimental configuration showing the laser-projected horizon. Experiment I did not use projected letters. Experiment II had letters projected 4 degrees above the center of the laser horizon. Experiment III had letters projected 30 degrees to the subjects right or left in alternating fashion.

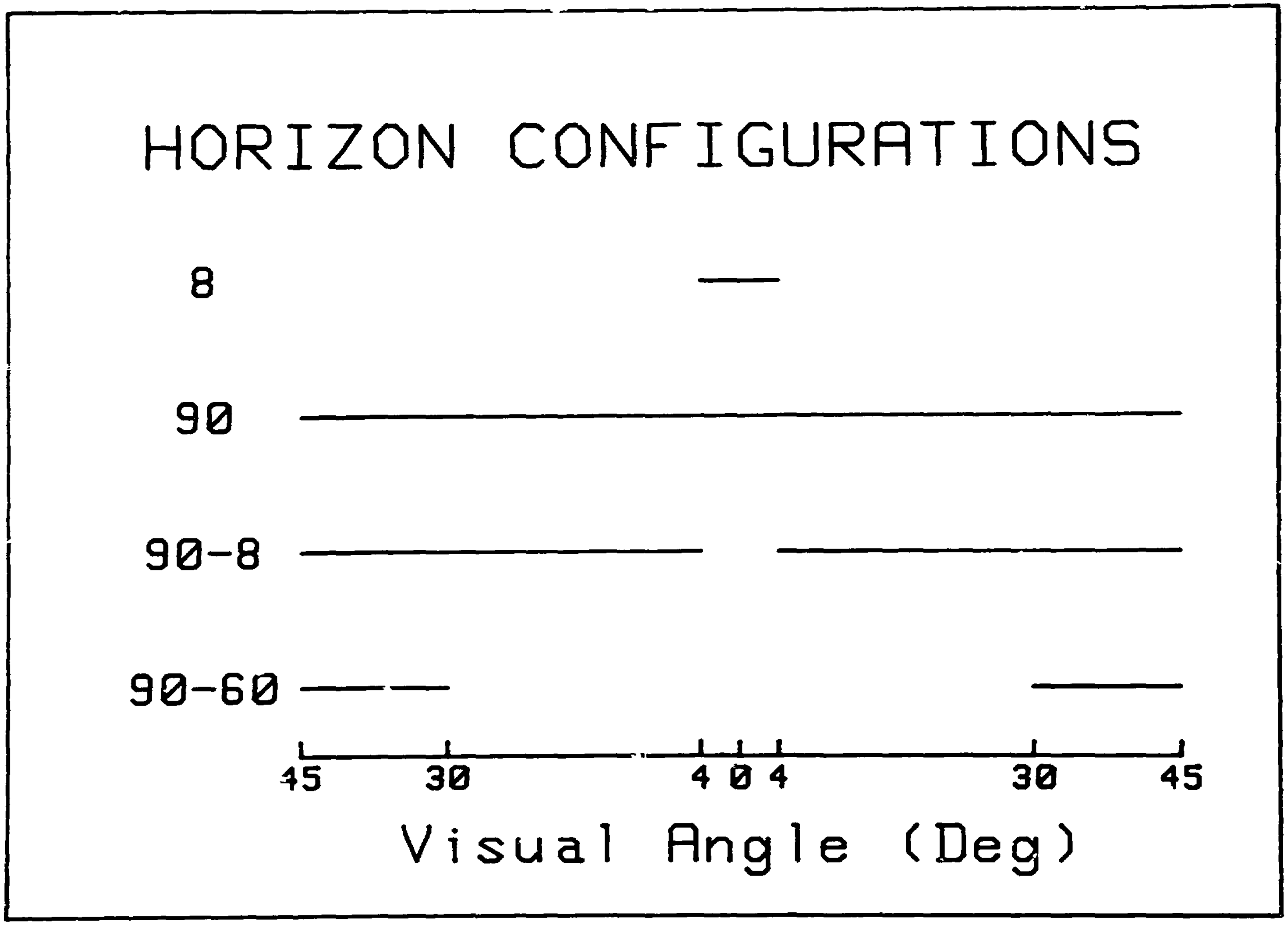

Figure 3. Four horizon configurations illustrating relative sizes.

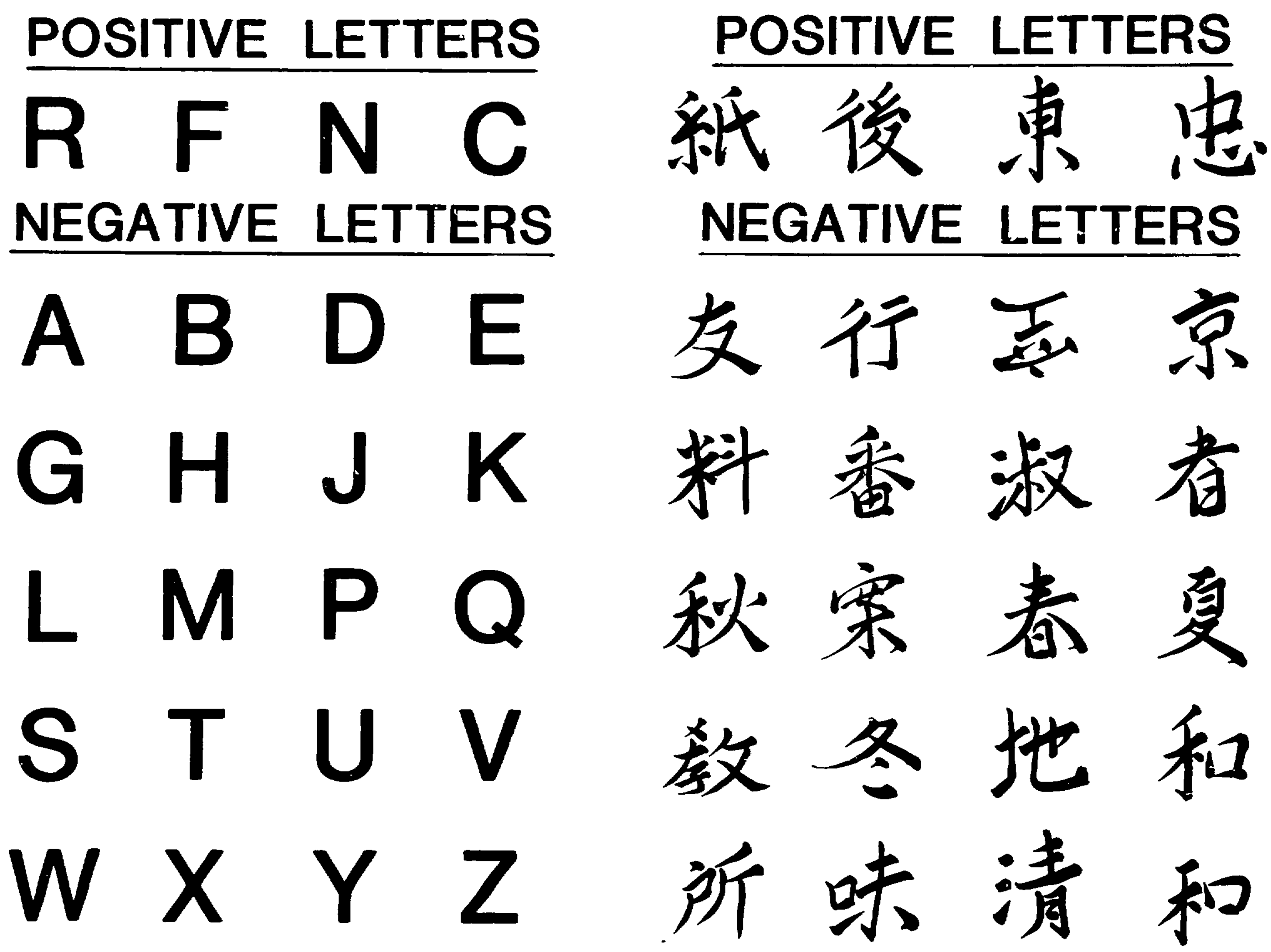

Figure 4. Positive and negative English (Experiment III) and Kanji letter sets (Experiments II and III).

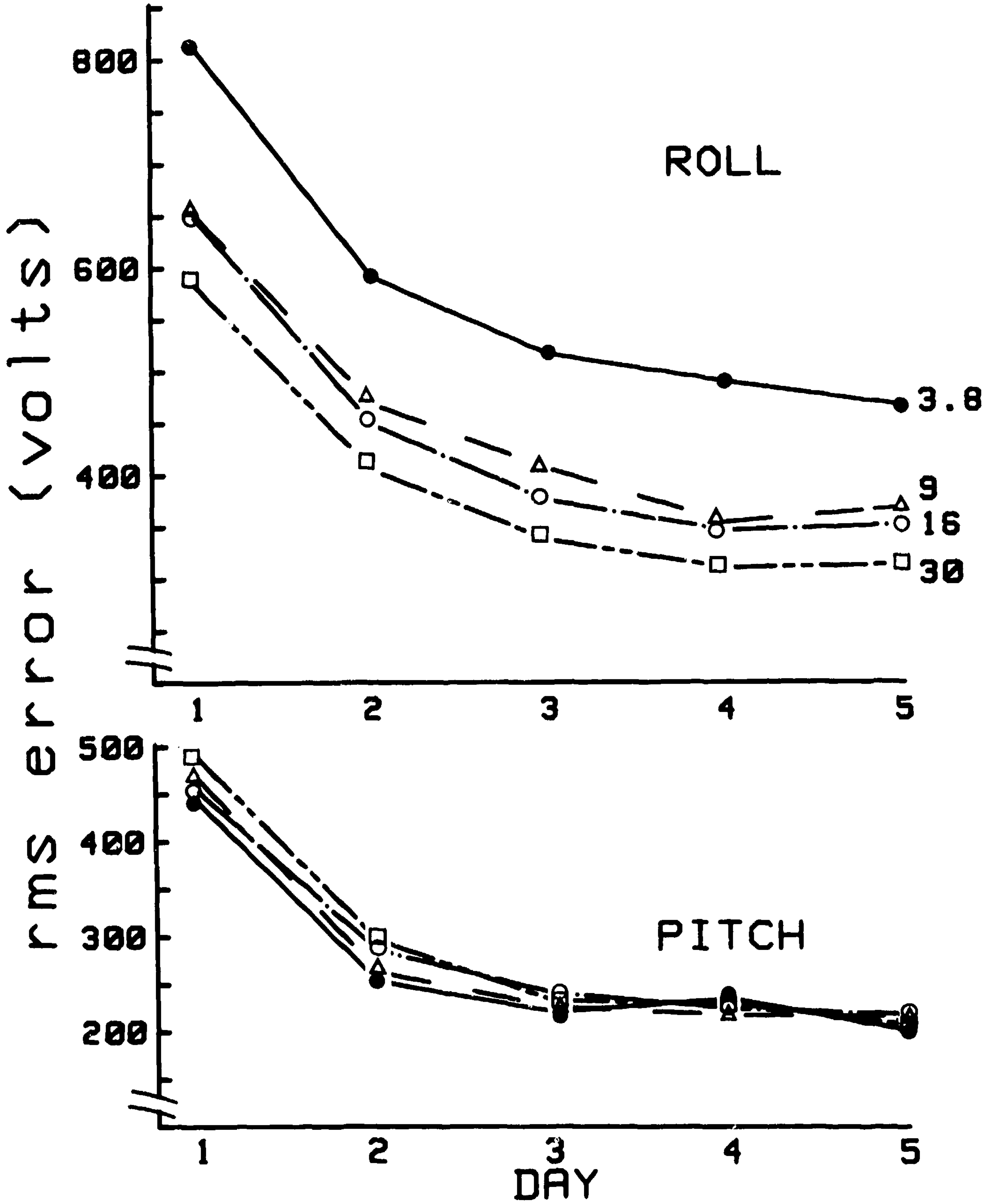

Figure 5. Roll and pitch axis rms tracking error (volts) for horizon lengths of 3.8, 9, 16, and 30° of visual angle.